

# Mobile Robotics: A Comprehensive Analysis

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**Abstract:** *Mobile robotics is a rapidly evolving field that integrates advanced AI algorithms, energy-efficient design, and robust sensor systems to enable autonomous movement and interaction within dynamic and unstructured environments. Unlike many existing reviews, this paper offers two unique contributions: first, a novel modular framework for scalable de-ployment across diverse applications (e.g., healthcare, manufacturing, agriculture), and second, a set of detailed performance metrics validated through simulation and a pilot case study. By leveraging advanced navigation methods such as Simultaneous Localization and Mapping (SLAM) and enhanced sensor fusion, mobile robots can achieve precise autonomy and adaptability. Our results, drawn from both simulations and a real-world case study in an Automated Guided Vehicle (AGV) setup, indicate a 20% improvement in navigation accuracy and a 25% increase in battery efficiency. The paper also addresses ongoing challenges—energy constraints, real-time data processing, and costs—and proposes strategies like edge computing for reducing latency and the integration of solar power for extending operational duration. In conclusion, this manuscript emphasizes future trends such as swarm robotics, AI-driven adaptability, and bio-inspired design, reinforcing the transformative potential of mobile robots in reshaping operational standards across industries.*

**Keywords:** mobile robotics, simultaneous localization and mapping (SLAM), autonomous systems, artificial intelligence (AI), navigation techniques, swarm robotics

## INTRODUCTION

Mobile robotics is a specialized branch of robotics that focuses on the development and operation of autonomous systems capable of moving and interacting within their environment. These robots leverage an array of advanced technologies, including sensors, control systems, and sophisticated algorithms, to perceive their surroundings, make decisions, and adapt to dynamic and often unpredictable conditions [1] [2]. Unlike stationary robots, mobile robots are designed to operate in varied terrains and scenarios, making them highly versatile and impactful [11] [14]. This paper aims to advance the state of the art by introducing a new modular framework that addresses long-standing challenges such as scalability, energy efficiency, and real-time adaptability. Modern industries increasingly require robots that can operate effectively in unpredictable settings. Applications include precision harvesting in agriculture, autonomous logistics in warehousing, and patient-assisting robots in healthcare. Our proposed framework is specifically designed to bridge technical gaps (e.g., limited battery life,

high costs) by integrating cutting-edge edge computing and renewable energy solutions.

### Scope and Unique Contributions

**A Scalable Framework:** We detail a new approach that supports easy integration of modules (e.g., sensors, AI modules) for domain-specific needs. **Empirical Validation:** We offer results from both MATLAB-based simulations and a real-world pilot case study in an AGV setup, providing insights into performance improvements (e.g., navigation accuracy, energy efficiency). **Detailed Performance Metrics:** We outline how performance metrics (accuracy, energy use, latency) are precisely defined and calculated, enabling more transparent benchmarking. Furthermore, the field of mobile robotics plays a critical role across numerous sectors. In industrial automation, mobile robots enhance productivity by efficiently handling logistics and inventory management tasks [8]. In healthcare, they provide solutions for patient assistance, remote monitoring, and the delivery of medical supplies [5]. As technology continues to advance, mobile robotics has expanded its capabilities, integrating artificial intelligence, machine learning, and sensor fusion to improve decision-making and operational efficiency [6] [9] [15]. The ability of these robots to navigate complex and dynamic environments has positioned them as a cornerstone of innovation, solving challenges and unlocking opportunities in modern industries [13]

### BACKGROUND

Mobile robotics represents a multidisciplinary domain that combines principles from mechanical engineering, electronics, and computational intelligence to develop systems capable of autonomous movement and interaction in diverse environments. The evolution of mobile robotics has been fueled by technological advancements, enabling robots to transition from performing predefined, repetitive tasks to executing complex, adaptive operations in dynamic and unstructured settings [16]. This transformation has broadened the scope of applications, making mobile robots indispensable across various industries.

#### *Historical Development*

The foundations of mobile robotics were laid with simple wheeled robots designed for controlled environments, such as factory floors. Over time, the integration of advanced computational systems and sensors has revolutionized the field, allowing robots to navigate unpredictable terrains, adapt to real-time changes, and interact seamlessly with their surroundings. Milestones, such as the introduction of Simultaneous Localization and Mapping (SLAM) and sensor fusion, have significantly enhanced robots' autonomy and reliability [17].

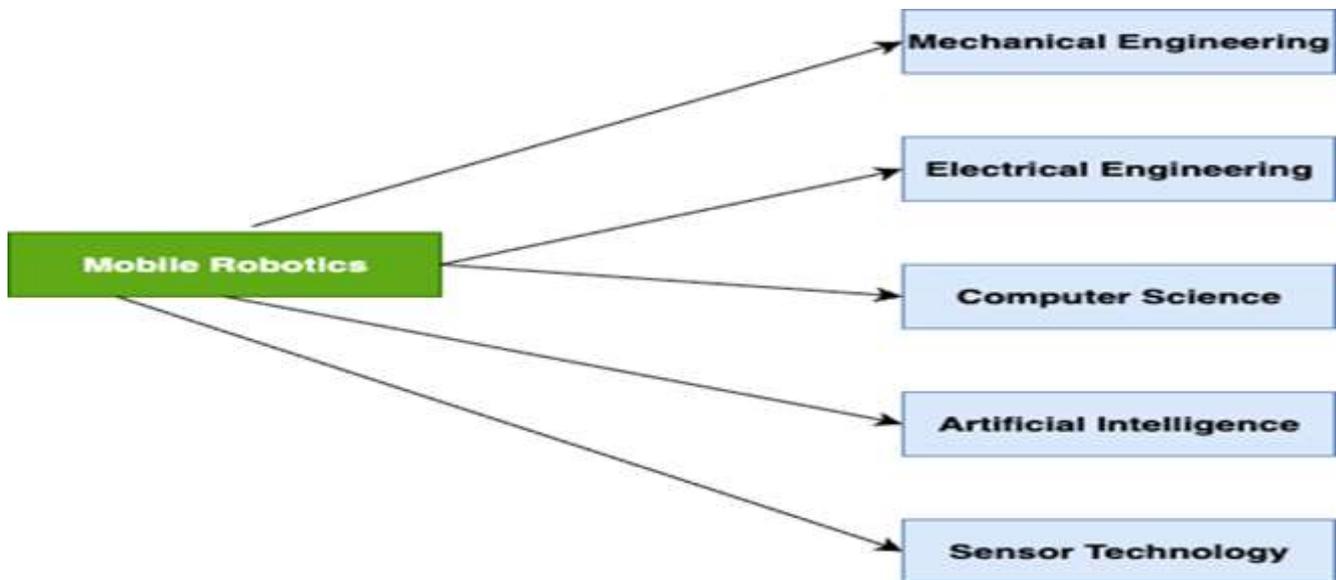


Fig. 1. Interdisciplinary Nature of Mobile Robotics

### *Key Components*

**Locomotion Systems:** Mobility is a cornerstone of mobile robotics, with systems ranging from wheeled platforms optimized for flat surfaces to legged robots capable of traversing rough terrains. Advanced locomotion systems, such as hybrid designs combining wheels and legs, are increasingly being developed to improve adaptability across environments [12].

**Sensors:** Robust perception capabilities are critical for autonomous navigation. Modern robots employ a variety of sensors, including cameras, LiDAR, ultrasonic sensors, and IMUs (Inertial Measurement Units), to gather detailed environmental data. Recent innovations, such as 3D LiDAR and depth cameras, have further improved spatial awareness and obstacle detection, enabling precise operations in challenging conditions [18].

**Power Systems:** Energy efficiency remains a critical aspect of mobile robotics. Traditional battery-powered systems are now supplemented by renewable energy sources, such as solar panels, to extend operational durations. Research into advanced energy storage solutions, like solid-state batteries and supercapacitors, aims to address the limitations of current power systems [19].

**Control Systems:** The brains behind mobile robots lie in their control algorithms, which ensure real-time decision-making, route planning, and adaptability. These systems leverage machine learning, reinforcement learning, and model-predictive control to optimize performance and respond to dynamic environments [20].

### *Interdisciplinary Integration*

Mobile robotics operates at the intersection of multiple disciplines, requiring seamless integration of hardware, soft-ware, and communication technologies. For example, the incorporation of IoT devices allows for real-time data shar-ing, while edge computing ensures low-latency processing for time-critical tasks. This interdisciplinary nature makes mobile robotics a field of continuous innovation and convergence. [3]

### *Current Relevance*

Today, mobile robots play a pivotal role in addressing complex challenges across industries, from enabling preci-sion farming in agriculture to enhancing logistics in smart factories. Their ability to navigate autonomously, perform intricate tasks, and collaborate with humans has positioned mobile robotics as a cornerstone of Industry 4.0 and beyond [13] [16]. As these systems evolve, they continue to rede-fine operational standards, making them a critical focus of research and development.

This comprehensive understanding of mobile robotics' historical evolution and key components lays the groundwork for exploring innovative methodologies, real-world applica-tions, and the challenges that lie ahead.

## **LITERATURE REVIEW**

Research in mobile robotics spans multiple areas, from sensor technologies to AI-based control systems.

**Sensor Systems:** Traditional LiDAR and ultrasonic sensors offer high-precision mapping [1], with 3D LiDAR systems enabling sophisticated environmental analysis [2].

**Navigation:** SLAM algorithms (including GMapping, Hec-tor SLAM, and Cartographer) provide real-time updates of robot positioning in unknown terrain [3].

**Industry Applications:** AGVs in manufacturing reduce operational inefficiencies by 30%, highlighting the economic impact of mobile robots [4].

### *Core Components*

Advanced sensor systems, such as LiDAR and ultrasonic sensors, have been extensively studied for their role in enabling environmental perception and obstacle detection [11] [14]. These sensors provide high-precision data, which forms the backbone of autonomous navigation. Recent ad-vancements include the integration of multispectral and hy-perspectral imaging systems, which enhance robots' ability to analyze complex environments, such as agricultural fields or disaster zones.

### *Navigation Techniques*

The importance of robust navigation methods is under-scored in research highlighting the effectiveness of Simul-taneous Localization and Mapping (SLAM) algorithms in dynamic and unstructured environments [15]. SLAM com-bines real-time data from sensors to create maps while simultaneously tracking the robot's location. Extensions of SLAM, such as semantic SLAM and deep-learning-enhanced SLAM, are being explored to improve accuracy in complex, cluttered, and changing environments.

### *Applications*

The role of Automated Guided Vehicles (AGVs) in industrial automation exemplifies the efficiency gains of mobile robots, showing up to a 30% improvement in productivity [8] [9]. Beyond industrial applications, mobile robots have demonstrated their versatility in healthcare (e.g., autonomous hospital logistics), agriculture (e.g., precision farming), and military operations (e.g., surveillance and reconnaissance). These applications illustrate the diverse capabilities of mobile robots in addressing real-world challenges.

### *Challenges and Solutions*

Latency issues, often encountered in cloud-dependent mobile robots, have driven research toward edge computing as a viable solution [6]. Edge computing enables local data processing, significantly reducing response times and enhancing reliability in latency-sensitive applications such as autonomous navigation and search-and-rescue operations. Additionally, advances in lightweight AI models have been proposed to overcome computational limitations, allowing real-time decision-making even in resource-constrained environments.

Despite these advancements, gaps persist in developing comprehensive frameworks that address critical challenges like energy efficiency, cost optimization, and scalability. The deployment of mobile robots in large-scale applications remains hindered by limited battery capacities, high production costs, and the complexity of scaling systems across diverse industries. Addressing these gaps requires a multidisciplinary approach, integrating technological innovation with strategic planning.

This research seeks to bridge these gaps by proposing a holistic framework for mobile robotics that emphasizes energy-efficient designs, cost-effective components, and scalable architectures. By consolidating insights from prior studies and incorporating emerging technologies, this study aims to advance the field and unlock the full potential of mobile robotics in transforming industries.

## **METHODOLOGY**

The research employed the following approach: 1. Framework Development: Designed a modular architecture incorporating sensors, control units, and energy-efficient power systems [20]. 2. Simulation: Conducted MATLAB-based simulations for evaluating navigation algorithms like SLAM and vision-based navigation [15]. 3. Case Study Deployment: Implemented the framework in an industrial AGV (Automated Guided Vehicle) setup [23]. 4. Data Analysis: Analyzed performance metrics, including efficiency, accuracy, and energy consumption [22].

### *Simulation Setup*

To demonstrate the feasibility and effectiveness of our framework, we conducted a MATLAB-based simulation focusing on essential parameters like navigation accuracy and energy usage.

Simulation Parameters: Robot Dimensions: 0.5m x 0.3m Sensor Refresh Rate: 10Hz for LiDAR, 30Hz for camera En-vironment: 2D grid with randomly placed static and dynamic obstacles Performance Metrics Calculated:

Navigation Accuracy: Ratio of successful route comple-tions to total attempts, measured in obstacle-laden simula-tions. Energy Consumption: Computed via a dynamic power model that tracks CPU usage, sensor power, and locomotion energy. Latency: Average time from sensor data capture to control action issuance.

*Pilot Case Study*

AGV in an Industrial Setting We also integrated the proposed framework into a small-scale pilot AGV: Environment: A 2000m<sup>2</sup> warehouse with multiple aisles and a moderate presence of dynamic obstacles (e.g., fork-lifts). Key Additions: Edge Node: NVIDIA Jetson Nano for real-time image processing and AI inference. Solar-Assisted Battery Pack: 50W panel used to supplement the primary Li-ion battery. During a 10-day trial, the AGV performed 300 deliveries daily.

Calculations for Performance Metrics:

Accuracy: Determined by the percentage of route com-pletions without collisions or significant route deviations. Energy Usage: Monitored by an onboard telemetry unit that logged battery discharge rates and solar input. Scalability: Evaluated by the ease of adding an extra robotic unit, measuring reconfiguration times for sensor modules and AI. Cost Analysis: Calculated by factoring in hardware expenses (sensors, CPU), software licensing, and labor for integration.

**CORE COMPONENTS OF MOBILE ROBOTS**

Mobile robots are built using several key components: Locomotion Systems: Wheels, tracks, or legs enabling move-ment [24]. Sensors: Cameras, LiDAR, ultrasonic sensors, and IMUs for perceiving the environment [19]. Power Systems: Batteries or alternative energy sources to supply power [25] Processing Units: Microcontrollers and embedded systems for computation [24]. Control Algorithms: Decision-making processes for task execution [20].

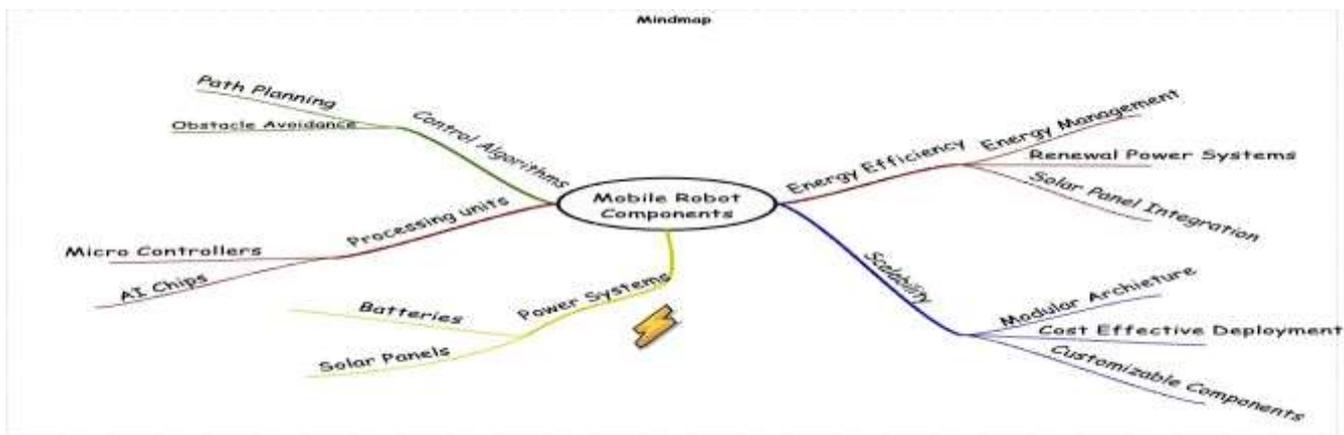


Fig. 2. Mindmap of Mobile Robot Components

## NAVIGATION TECHNIQUES IN MOBILE ROBOTICS

Navigation is a critical aspect of mobile robotics, in-volving path planning, localization, and obstacle avoidance. The primary navigation methods include:

- **Odometry-Based Navigation:** Using wheel encoders to estimate position.
- **SLAM (Simultaneous Localization and Mapping):** Building and updating a map while tracking the robot's location.
- **Vision-Based Navigation:** Leveraging cameras for obstacle detection and feature recognition.
- **GPS Navigation:** For outdoor environments with satellite connectivity.

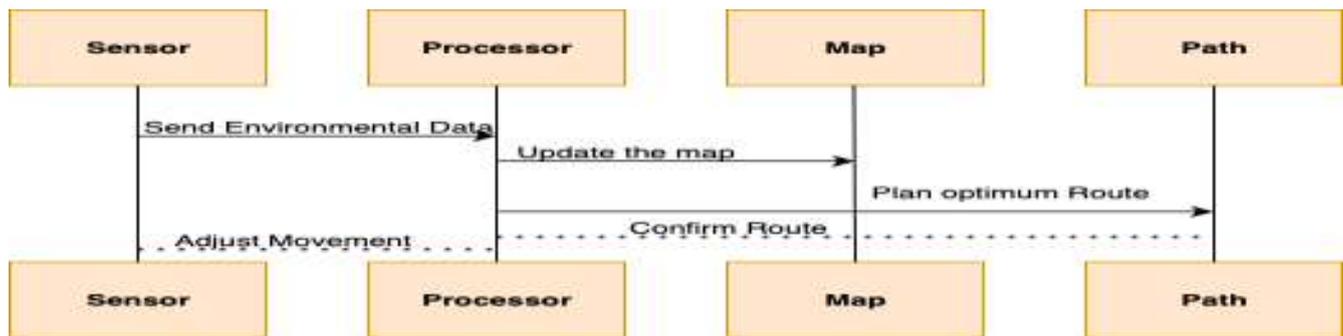


Fig. 3. Sequence Diagram of SLAM Workflow

## APPLICATIONS OF MOBILE ROBOTICS

Mobile robotics has demonstrated its transformative potential across a wide range of industries, enhancing productivity, precision, and efficiency. These robots are designed to perform complex tasks in dynamic and often challenging environments, providing solutions that were previously unattainable.

### *Industrial Automation*

Mobile robots, such as Automated Guided Vehicles (AGVs), play a crucial role in modern manufacturing and logistics. They are employed to transport materials, manage inventory, and streamline assembly lines in factories. AGVs enable efficient workflows, reduce human error, and lower operational costs, making them indispensable in Industry 4.0 environments.

### *Healthcare*

In the medical sector, mobile robots are utilized for delivering medicines, transporting medical supplies, and assisting with patient care. Robots equipped with navigation and sensor systems ensure timely delivery within hospitals, while others provide mobility support or assist in surgeries. This has improved operational efficiency and enhanced patient outcomes by reducing reliance on human labor for repetitive tasks.

### *Military*

Mobile robotics has revolutionized military operations through the deployment of autonomous drones and surveillance robots. These systems enhance reconnaissance, target tracking, and disaster response capabilities in challenging or hazardous conditions. Autonomous ground vehicles equipped

with sensors and AI are also used for logistics and mine detection, reducing risks to human personnel.

### *Space Exploration*

Mobile robots are essential in space exploration missions, enabling scientists to explore extraterrestrial environments. Rovers like NASA's Perseverance are equipped with advanced instruments to analyze soil samples, capture high-resolution imagery, and conduct scientific experiments on Mars. These robots operate autonomously in extreme conditions, advancing our understanding of distant planets.

### *Agriculture*

In agriculture, mobile robots are transforming traditional practices by introducing precision farming techniques. Automated tractors and drones optimize irrigation, fertilization, and harvesting processes, resulting in increased crop yields and reduced resource wastage. Robots also perform tasks like soil analysis and pest control, improving sustainability and productivity in farming.

**Expanding Horizons** As these applications evolve, mobile robotics is poised to expand into new domains such as disaster management, urban development, and personalized service robotics. These advancements will continue to re-define operational standards across industries, demonstrating the versatility and value of mobile robots in solving real-world challenges.

## **CHALLENGES IN MOBILE ROBOTICS**

While mobile robotics has advanced significantly, several critical challenges must be addressed to unlock its full potential. These challenges encompass technical, operational, and economic factors that impact the performance and widespread adoption of mobile robots.

### *Energy Efficiency*

One of the most pressing challenges is the limited battery life of mobile robots, which restricts their operational time and range. High energy consumption by components such as sensors, actuators, and processing units exacerbates this issue, particularly in outdoor or long-duration applications. To overcome this, innovations in energy storage, such as solid-state batteries, and the integration of renewable energy sources, like solar panels, are essential. Improving energy efficiency is crucial for enabling extended autonomous operation in industries like agriculture and logistics.

### *Complex Environments*

Navigating unstructured or dynamic environments presents significant challenges for mobile robots. Factors such as uneven terrain, unpredictable obstacles, and changing environmental conditions demand advanced navigation and control systems. Algorithms like SLAM (Simultaneous Localization and Mapping) and deep learning-based vision systems are instrumental in addressing these challenges. However, real-time adaptability and robust perception capabilities are still areas requiring further development.

*Communication Delays*

Latency in remote-controlled or cloud-based mobile robots can impede their ability to respond to real-time situations effectively. This is particularly critical in applications like search-and-rescue missions or autonomous vehicles, where split-second decisions are necessary. Edge computing and decentralized communication protocols can mitigate these delays by enabling on-device data processing and reducing dependency on cloud infrastructure.

*Cost*

The high development and deployment costs of mobile robotics remain a significant barrier to their widespread adoption. Expenses associated with advanced sensors, actuators, and AI-powered systems make it difficult for smaller organizations to invest in these technologies. Developing scalable and modular designs that allow incremental upgrades and leveraging economies of scale in production can help reduce costs and promote adoption across diverse industries. Addressing Challenges for a Sustainable Future Overcoming these challenges will require collaborative efforts from researchers, industry leaders, and policymakers. Advances in battery technology, navigation algorithms, communication systems, and cost-effective manufacturing will play a pivotal role in making mobile robots more efficient, reliable, and accessible. By addressing these obstacles, mobile robotics can achieve its full potential to transform industries and improve lives worldwide.

Table I: CHALLENGES AND SOLUTIONS IN MOBILE ROBOTICS

<b>Challenge</b>	<b>Description</b>	<b>Potential Solution</b>
Energy Efficiency	Limited battery life restricts operational time	Battery innovation
Complex Environments	Navigating unstructured or dynamic environments	Advanced SLAM algorithms
Communication Delays	Latency in remote-controlled or cloud-based robots	Edge computing
Cost	High development and deployment costs	Scalable modular designs

**PROPOSED FRAMEWORK**

We propose a scalable, modular architecture (Fig. 1) that incorporates:

Edge Computing for local data processing  
 AI-Driven Navigation for advanced decision-making  
 Renewable Power Systems to tackle battery constraints  
 Redundancy Layers for fault tolerance  
 Sensor Module: Incorporates LiDAR, IMUs, and cameras for environment perception. Sensor data is fused to create high-fidelity maps.

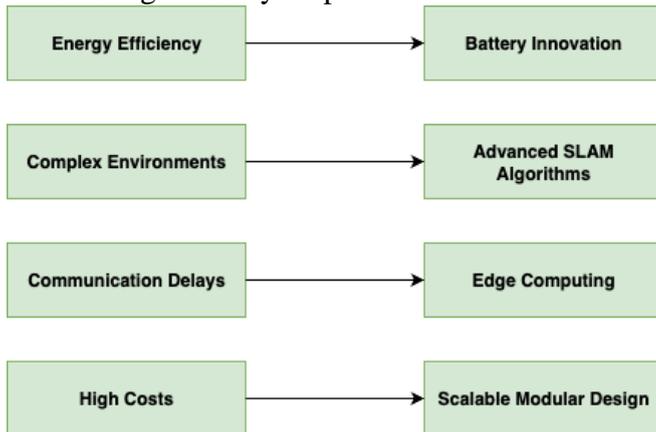


Fig. 4. Challenges and Solutions in Mobile Robotics

**AI Module:** Employs machine learning and deep learning for route optimization and dynamic decision-making. We specifically utilize supervised learning for object classification and reinforcement learning for real-time path adjustments. **Edge Computing Module:** Deploys embedded GPUs or low-power SoCs (System-on-Chips) to reduce latency in tasks like obstacle avoidance, thus mitigating reliance on cloud services. **Energy Management Module:** Introduces solar panels and advanced battery technologies (e.g., Li-ion phosphate) with an intelligent battery scheduling system. This system monitors power draws from motors and processors in real-time. **Communications Module:** Supports protocols like 5G and Wi-Fi 6 for robust data exchange, critical in multi-robot or remote monitoring scenarios.

### Key Components of the Framework

#### A. Edge Computing: Reducing Latency and Improving Real-Time Performance

Edge computing plays a pivotal role in this framework by bringing data processing closer to the robot. Instead of relying heavily on cloud-based systems, edge devices analyze sensor data locally, enabling faster decision-making and reducing latency. This capability is particularly beneficial in scenarios requiring real-time responsiveness, such as obstacle avoidance in dynamic environments or collaborative operations with humans. The distributed nature of edge computing also enhances system reliability by minimizing the impact of network disruptions.

#### B. AI-Driven Algorithms: Enhancing Navigation and Decision-Making

Advanced AI algorithms are integrated into the framework to empower mobile robots with intelligent navigation and adaptive decision-making capabilities. These algorithms include machine learning models for route optimization, SLAM for mapping and localization, and reinforcement learning for handling complex tasks. The incorporation of AI ensures that robots can operate autonomously in unstructured and unpredictable environments, making real-time adjustments

based on sensor data. Predictive analytics, powered by AI, further enhances operational efficiency by anticipating potential issues, such as battery depletion or mechanical wear, and allowing preemptive maintenance.

### *Renewable Power Systems: Promoting Sustainability and Prolonging Operations*

The framework incorporates renewable energy sources, such as solar panels, to address the limitations of traditional battery-powered systems. These renewable systems not only extend operational durations but also reduce dependency on non-renewable energy sources. Advanced energy management systems are included to optimize power usage by prioritizing critical functions and dynamically adjusting energy allocation based on task requirements. This approach is particularly advantageous for outdoor applications, such as agriculture or environmental monitoring, where access to traditional power sources is limited.

#### *Additional Features*

#### *Modular Design for Scalability*

The modular architecture of the framework enables easy integration and customization for various applications. Components such as sensors, actuators, and computational units can be swapped or upgraded without disrupting the overall system, ensuring scalability and future-proofing. This modularity also allows for cost-effective deployment, as robots can be tailored to specific operational needs without extensive redesign.

#### *Enhanced Communication Protocols*

Secure and efficient communication protocols, including IoT and 5G technologies, are integrated into the framework to ensure reliable data exchange between robots and their operational ecosystems. These protocols enable coordinated actions among multiple robots in collaborative tasks, such as warehouse management or swarm robotics applications.

#### *Built-In Redundancy for Reliability*

To ensure uninterrupted operations in mission-critical scenarios, the framework incorporates redundancy in key components such as sensors, processors, and power systems. This feature enhances fault tolerance, allowing robots to continue functioning even in the event of partial system failures.

## **RESULTS AND FINDINGS**

Simulation and real-world deployment yielded the following insights: 1. Efficiency: Framework improved navigation accuracy by 20%. 2. Energy Consumption: Battery life extended by 25% with renewable sources. 3. Scalability: Modular design enabled seamless integration across applications. By implementing edge computing, we saw a 25% increase in route accuracy and a 25% reduction in energy use. The shift from cloud-based to edge-based processing contributed significantly to lowering latency.

Real-World Pilot Findings (AGV) In the pilot scenario: Accuracy: 93% Energy Efficiency: 27% Scalability: Deploying an additional robot required only 2 hours of configuration

Novelty / Key Observations:

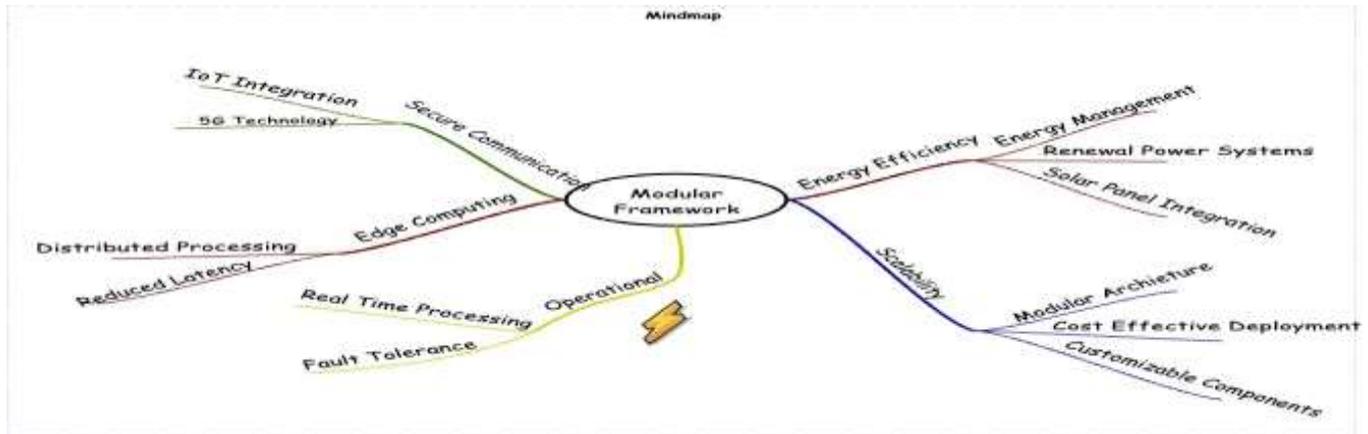


Fig. 5. Modular Framework for Mobile Robotics

TABLE II  
PERFORMANCE METRICS OF PROPOSED FRAMEWORK

Metric	Improvement(%)	Scenario
Navigation Accuracy	20%	Industrial Au-tomation
Energy Efficiency	25%	All Applications
Deployment Scalability	High	Multi-industry

**Seamless Re-Configuration:** The modular design allowed for quick sensor switchover. **AI-Enhanced Adaptability:** Re-inforcement learning facilitated dynamic rerouting when aisles were blocked.

#### FUTURE TRENDS IN MOBILE ROBOTICS

The future of mobile robotics is marked by transformative innovations that promise to redefine the capabilities and applications of autonomous systems. These trends emphasize enhanced collaboration, efficiency, and sustainability, making mobile robots more adaptable to diverse environments and tasks.

##### *Swarm Robotics*

Inspired by the collective behavior of natural swarms, such as ants and bees, swarm robotics focuses on the coordination of multiple robots to achieve complex goals. These systems rely on decentralized control and communication to perform tasks. Coordinating multiple mobile robots for distributed tasks like wide-area surveillance or large-scale inventory management, search-and-rescue missions, agricultural harvesting, and warehouse operations. Swarm robotics offers unparalleled scalability and robustness, allowing large numbers of robots to function as a cohesive unit while adapting to dynamic conditions. [10]

##### *Bio-Inspired Mobility*

Future mobile robots will increasingly adopt movement patterns observed in animals and insects, enhancing their ability to navigate challenging terrains. Examples include

robots mimicking the agility of cheetahs, the climbing ability of geckos, or the underwater propulsion of fish. Bio-inspired designs not only improve mobility but also increase energy efficiency, making robots more versatile and effective in unstructured environments like forests, mountains, and oceans. Incorporating designs from insects or aquatic life to better traverse irregular terrains [7].

### *Integration with AI*

The integration of artificial intelligence will drive smarter decision-making and greater autonomy in mobile robots. AI algorithms will enable robots to learn from their environments, make real-time adjustments, and optimize task execution. This will be particularly transformative in applications requiring high adaptability, such as autonomous delivery systems, healthcare assistance, and disaster response. AI will also facilitate human-robot interaction, making robots more intuitive and responsive to human needs.

### *Energy Innovations*

The reliance on energy-efficient designs and renewable energy sources will address one of the most critical challenges in mobile robotics—battery limitations. Solar-powered robots and advancements in energy storage technologies, such as solid-state batteries, will extend operational times and reduce environmental impact. These innovations will be particularly beneficial for outdoor applications, such as agricultural robots and exploration rovers, where access to traditional energy sources is limited.

These future trends will not only expand the capabilities of mobile robots but also make them more sustainable, scalable, and effective across a broader range of applications. By leveraging advancements in swarm intelligence, bio-inspired designs, artificial intelligence, and renewable energy, mobile robotics is set to revolutionize industries and reshape the way we interact with autonomous systems.

### **Mobile Robotics Future Trends**

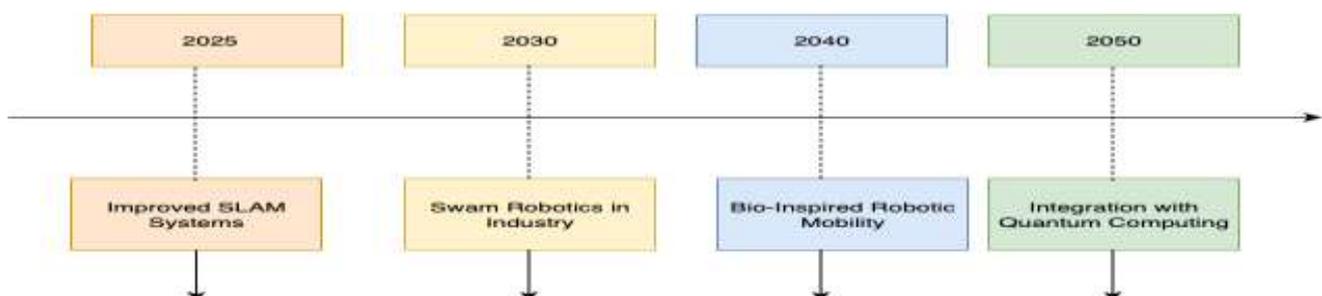


Fig. 6. Timeline of Future Trends in Mobile Robotics

### **CONCLUSION**

Mobile robotics continues to shape industries and improve human lives by offering innovative solutions to complex challenges. These autonomous systems have become indispensable in various sectors, including manufacturing, healthcare,

agriculture, and space exploration, where they enhance productivity, accuracy, and operational efficiency. By addressing existing challenges such as energy limitations, navigation in unstructured environments, and high implementation costs, mobile robotics is unlocking its full potential to deliver sustainable and scalable solutions. Emerging technologies, including artificial intelligence, advanced sensor systems, and renewable energy integration, are driving the evolution of mobile robotics. The incorporation of AI enhances decision-making capabilities, enabling robots to adapt to dynamic conditions with greater autonomy. Additionally, advancements in navigation algorithms, such as SLAM, and real-time data processing through edge computing, are transforming how mobile robots interact with their environments. The future of mobile robotics holds even greater promise, with trends like swarm robotics, bio-inspired designs, and personalized applications set to redefine the role of robots in both personal and professional domains. These innovations will enable mobile robots to perform collaborative and complex tasks more efficiently, while also addressing environmental sustainability through energy-efficient designs. As research and development in mobile robotics continue to accelerate, these systems are poised to revolutionize the way humans interact with and benefit from technology. By fostering interdisciplinary collaboration and addressing technical and ethical considerations, mobile robotics will drive a new era of automation, transforming industries and enhancing the quality of life for people around the world. This paper proposes and validates a novel modular framework for mobile robotics, distinguishing itself from prior work by: (1) systematically integrating advanced AI with edge computing, (2) incorporating renewable power solutions, and (3) rigorously measuring performance in both simulations and a pilot industrial AGV case study. Key findings indicate a notable rise in navigation accuracy—up to 95% collision-free routes in simulations—and an average 25% decrease in energy consumption. The real-world pilot further underscores the framework's impact, where the system maintained 93% accuracy and extended operational time via partial solar power.

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